01: INTRODUCTION to FORENSIC TOXICOLOGY

***"Everything is poison, there is poison in everything.***

***Only the dose makes a thing not a poison."*** ***-Paracelsus***

Peggy and Pye Carr lived in a rural part of Florida with four of their children. In July 1988, they received an anonymous warning to move out of Florida or the family would all die. The family dismissed the warning as a teenage prank, although Peggy warned her children to be careful. Life went on as normal until October 1988, when Peggy began experiencing severe pain and was taken to the emergency room. Doctors were unsure about what was causing the problem, but when the pain began to go away, she was sent home.

Within days of returning home, not only did Peggy's symptoms return but several of the children were also experiencing pain. Peggy was rushed to another hospital and this time, one of the doctors suspected that the cause of the pain might be poison. The doctor believed that thallium, a colorless and odorless poison, might be what was causing the problems for the Carr family. The family was tested and Peggy and two of her sons had high levels of thallium in their systems. Pye Carr didn't really believe the results, saying that no one disliked the family enough to kill them. When the police were notified, Pye became one of the top suspects for the crime. However, more tests revealed that Pye and two other family members also had thallium in their systems, but at lower levels. Although the two sons would recover, Peggy died in March 1989 from thallium poisoning.

Investigators combed the house looking for the source of the poison. They took more than 400 items to the lab to test for thallium. Soon, it was noted that three bottles of Coca-Cola had their caps tampered with. Testing revealed the bottles contained thallium. The family had been consuming bottles of soda that had been poisoned with thallium. Law enforcement officials began to hone in on the Carrs' neighbor George Trepal when some of his interview answers revealed a possible link to the threatening note that the Carr family had received. Members of Mensa, an organization for individuals with IQs in the top two percent of the population, George and his wife were highly intelligent and studied forensic and police procedures for mystery weekends that they attended. Forensic scientists were eventually able to link the Trepals' house to thallium and found information about poisons and a bottle capping device at his home. Trepal was arrested, convicted, and sentenced to death for the poisonings.

02: FORENSIC TOXICOLOGY

**Toxicology** is the study of substances that cause adverse effects in humans or other organisms. In other words, toxicology involves the study of poisons, toxins, and other chemicals that create adverse symptoms or reactions in humans. This might range from common substances such as alcohol or poisons such as arsenic. **Forensic toxicology** is the use of toxicology in the process of investigating deaths, drug cases, or suspected poisonings. Forensic toxicology involves not only the area of toxicology, but also the use of areas such as analytic chemistry and pharmacology.

When thinking about poisons and toxins, we may be most likely to think of murder and intentional poisonings. However, poisons and toxins may also play a role in accidental deaths and in suicides. For example, forensic scientists may need to analyze the type and amount of a substance that a person has present in his or her body. Additionally, many substances that we might not think of as poisons can be used to harm or kill someone. In large doses, many prescription and over-the-counter medications can be harmful to humans. For example, aspirin can be toxic to humans if a large enough dose is taken or if a large dose is taken for an extended period of time. In fact, some scientists believe that the number of deaths during the 1918 Spanish flu pandemic was due in part to aspirin toxicity. Doctors at the time were giving patients fairly high doses of aspirin for periods of time, which can cause toxicity in about 25 percent of people.

Poisons and toxins have been used during crime for thousands of years. In fact, some of the most prolific serial killers known to us used poisons as their method of killing. Because of the wide variety of poisons and toxins, the variety of symptoms that might be present, and the ways of concealing these substances, forensic scientists have to be both observant and well-versed in the area. In most cases, a forensic scientist will be given bodily fluids (such as blood) or pieces of human organs. These samples are then tested for the presence of the suspected toxins or poisons. Forensic scientists may have some clue about what poison might be present in the samples from descriptions of a person's symptoms or possibly from containers that had been left at the scene. If the forensic scientist does not have these clues, he or she will have to screen for different poisons, which will hopefully help narrow does the possibilities.

Determining which poison or toxin is present in the samples can be a challenging one. Not only do forensic scientists have to identify a particular poison or toxin from the thousands that exist in the world, but they also have to do so with often just trace amounts of the poison or toxin. Think about what happens when you take an aspirin or other medication. After you ingest the substance, your body begins to metabolize that substance, which changes the chemical in the body from what it was to a chemical that can ultimately be eliminated from the body. In addition, the substance may be dispersed throughout the body so that only a very small portion of the substance can be found in any one place in the body, before it is eliminated. All of these aspects make finding and identifying a poison or toxin difficult.

03: THE HISTORY of FORENSIC TOXICOLOGY

Humans have long known that certain substances produce negative effects in the body. Human societies gradually gained knowledge about which plants and other natural materials were harmful to them, and which ones could be eaten or otherwise used. Groups also began using poisons and toxins for warfare, coating the tips of arrows or other weapons with poisonous substances. Around 2500 B.C., the Sumerians even worshipped a goddess of poison. By 500 B.C. doctors in India had started to create lists of known poisons and the effects that they might have on the body.

Poisons in the ancient world were used in a variety of ways. The Greeks, for example, used hemlock as a method of capital punishment. The philosopher Socrates was executed in this way. Ancient Romans often used poisons to kill off political or economic rivals. In fact, the practice became such a problem that the Roman Empire issued the world's first law against poisoning in 82 B.C.; other laws prohibited the cultivation of particular plants that could be used as poisons. In other parts of the world, poisons were used for government-sponsored political assassinations. In India, a type of secret service used female poisoners, who were able to get close to male victims before poisoning them.

Not surprisingly, as law enforcement and medical knowledge grew in society, the beginnings of forensic toxicology also grew. Poison was a popular method for killing individuals in the past, largely because it was hard to detect. Until fairly recently, the methods didn't exist to prove that someone had been poisoned, beyond the symptoms that the person experienced. Unless someone confessed to poisoning another or the symptoms were such that poison seemed likely, law enforcement officials and doctors often couldn't prove murder, or they labeled the death a natural death. Any convictions of poisoning that happened were because of the circumstantial evidence that was witnessed or found.

About 200 years ago, the foundations for modern forensic toxicology were laid. **Hermann Boerhaave,** a Dutch botanist and physician, suggested that poisons could be detected in a person's body through the use of chemical means. He thought that if substances were placed on very hot coals, the odors could then be tested for the presence of poisons. This is quite a reach to today's methods of testing for poisons, but it does reflect the idea that someone could test for poisons using an objective, standardized scientific process. In the late 1700s, **Joseph Plenic** suggested that detection and identification of poisons needed to occur through the organs of the body in order to be sure of poisoning.

By the 1800s, the area of toxicology began to grow and scientists began to gain greater understanding not only about poisons and toxins, but also how to detect them in the body. **Mathieu Orfila,** a Spanish-born chemist, published one of the first written works dedicated to the topic of poisons and medications. In his book, Orfila not only summed up what was known about various poisons and toxins at that time, but also sought to classify the poisons and toxins by their characteristics. He would become known as the "father of toxicology" for his work in the area.

One of the most common poisons used in the 1800s was arsenic, and Orfila worked on developing more reliable ways of identifying this poison. **Johann Daniel Metzger** had developed a method of detecting arsenic in solutions in the 1780s, but forensic scientists needed a way to detect arsenic and other poisons in human tissues and fluids. In the 1830s, a scientist named **James Marsh** developed a way to test for arsenic in tissue, and Orfila was able to use the test to identify arsenic from human tissue.

In the early twentieth century, forensic toxicology laboratories began to be established. The state of New York, for example, established the "Medical Examiner's Office and Toxicology Laboratory" in 1918. Many other cities and areas followed suit, which helped to increase the scholarship and research being done in the area of toxicology. However, even with forensic laboratories, poisonings still occur and go undetected. Today, some readily detectable poisons still go undetected, largely because there are no real routine procedures to test for poisons. If there is no suspicion of poison in the case, the body may not be tested for it. Since so many poisons mimic the effects of other health issues, the deaths may simply be labeled as something natural or accidental. While illegal drugs still constitute the greatest number of deaths by chemical means, poisons are the cause of some intentional and accidental deaths.

04: TYPES of POISONS

Since it is true that many different substances can cause harm to individuals if the dose is high enough, the list of possible poisons or toxins that a forensic scientist has to deal with is a long one. However, what we often think of as poisons are substances that are deadly to humans even in small doses. A smaller number of substances have characteristics that make them popular choices for murders. These characteristics include:

• Toxic or deadly in relatively small doses or quantities.

• Easily hidden taste or odor.

• Easily administered.

• Symptoms that either mimic other illnesses or occur some time after the poison is administered.

• Easily found and accessible.

When examining someone suspected of being poisoned, forensic scientists can gain information from where the highest concentrations of the drugs are. For example, if the highest concentration of a material is found in the lungs, it is likely that the person inhaled the poison. If the highest concentrations are in the gastrointestinal tract, it is likely that the person ingested the poison through their mouth. Let's take a look at some of the substances that meet most of these characteristics.

**Arsenic** has probably killed more individuals than any other poison. This substance is actually a common element, found in the crust of the earth as well as other natural locations, and most of the arsenic compounds found have little taste or odor. In fact, arsenic has been used in everything from paints to herbicides to a chemical warfare agent. This has made arsenic a popular substance for poisoners in the past, because it could be easily added to food or drinks without anyone noticing. Today, however, arsenic is easily identified in the forensic laboratory, and most of the intentional poisonings using arsenic today relate to pesticides or rodent poisons. The substance can have a number of adverse effects on humans, even in doses that are not legal. These include:

• Irritation to the stomach and intestines (which can cause pain in these areas, vomiting, and diarrhea).

• Peripheral nerve problems.

• Darkening skin, particularly on the soles of the feet and palms of the hand.

• The development of Mees lines (white lines) in fingernails and toenails.

One of the advantages for forensic scientists trying to detect arsenic poisoning is that arsenic tends to remain in the bones and hair of someone exposed long after their death. This has led to some past cases being solved after the bodies were exhumed and tested for arsenic.

Arsenic was used in many of the poisonings that occurred throughout history. During the Renaissance period in Europe, it was joked that no one could ever say that they had dinner with the infamous Borgia family, since no one ever lived to the next day. Lucrezia Borgia hid poison in a hollow ring, which she then used to poison rivals. Another infamous set of poisonings occurred after an Italian named Giulia Toffana created a cosmetic mixed with arsenic. Women bought the mixture as makeup and were informed about its "other" use. More than 600 individuals were eventually killed through this mixture until law enforcement caught up with Toffana in 1709.

**Cyanide** is another substance that has been used in some poisoning cases, including the infamous Jonestown massacre in 1978, where over 900 people died after consuming a cyanide-laced drink. It has several industrial uses, including photographic processing. Cyanide can also be produced by fires and is one of the causes of fire-related deaths, along with carbon monoxide. The criminal justice system has also sometimes used hydrogen cyanide to administer death in capital punishment cases. One form of cyanide is a colorless liquid. When the vapors from this deadly poison are inhaled, death can result within minutes. Cyanide can also occur in salt forms, which is typically the type used by individuals who are trying to intentionally poison someone. These salts have an odor and taste of bitter almonds. As a poison, cyanide essentially stops cellular respiration in the mitochondria, preventing cells in the body from using glucose to produce ATP. Symptoms can include headache, nausea, mental dysfunction, seizures, cardio or respiratory failures, and death.

**Strychnine** comes from the seeds of the strychnine tree, and strychnine poisoning can occur through consumption, inhalation, or absorption by mucous membranes. Although strychnine is colorless, it has a very strong bitter taste. Today, strychnine is used in some rodent poisons. The poison causes painful cramps and muscle contractions. These can resemble seizures and the individual is generally aware and in great pain while they occur. Death occurs as asphyxiation, after breathing is restricted.

The leading cause of both accidental and intentional poisoning in the United States is carbon monoxide. **Carbon monoxide** (CO) occurs when organic materials are not completely combusted. It is produced by many vehicles, for example, and expelled through the exhaust system. CO is colorless, odorless, and tasteless. It can create a poisoning situation through fires, faulty heating systems, automobile exhaust, and other related circumstances. Early symptoms of CO poisoning can include fatigue, worsening headache, and nausea. These can progress to confusion, coma, and death. Forensic scientists look for a reddish coloration to the skin, produced by a reddening of the blood with carbon monoxide poisoning.

Another poison that you may be less familiar with, but which was widely used in the past, is aconite. **Aconite** is also sometimes known as women's bane, wolfsbane, or monkshead, and it comes from the aconite plant. In the past, this substance was used to put convicted criminals to death, poison arrow tips, and even to poison enemies by placing it in their water supplies. A white powder, aconite produces a numb or tingling feeling when someone comes into contact with it. The feeling spreads throughout the body, producing muscle weakness, abnormal heart rhythm, and respiratory failure.

One of the poisons that is creating concern over its use as a potential terrorist weapon is ricin. **Ricin,** which occurs when castor oil is produced, is extremely poisonous when it is ingested or inhaled. This poison inhibits protein synthesis in humans and the symptoms differ slightly depending on how a person was poisoned. For example, inhalation tends to produce difficulty breathing, chest tightness, heavy sweating, and respiratory failure. Ingesting the poison leads to vomiting, diarrhea, seizures, and eventually organ failure.

05: DETERMINING a POISON

When poisoning is suspected or when a death has occurred that seems suspicious, forensic scientists have the task of determining whether poisoning happened and what poison was used. At times, the crime scene or the body of the person will point to particular poison or toxin. However, in many cases, the poison or toxin is unknown and the forensic scientist must use his or her knowledge of poisons and their effects, along with tests, to determine what happened.

Within the laboratory, samples must be taken to determine whether poison is present. The samples taken may depend on whether the individual is alive at the time of testing or whether he or she has already died. For example, while blood can be easily obtained from a living victim, it would be harder to use a piece of an organ from a potential poisoning victim who is living.

Handling samples of tissue, organ, or other bodily material postmortem (after death) can also be challenging. One reason for this is that the samples can vary widely in quality, and forensic scientists need to know what type of sample will provide them with the best information. For example, postmortem samples can be in varying stages of decomposition, so that factor has to be taken into account.

The type of sample taken from the body is dependent on a number of different factors. This can include the length of time that the individual has been dead, the type of poison suspected, and where certain poisons are most likely to be found. Let's take a look at some of the specific sample types and their uses:

• Blood: This is one of the most useful toxicological samples. When dealing with postmortem samples, it is often best to take a blood sample away from the heart, since blood taken from the heart may have artificially high levels of toxins that wouldn't reflect the amount distributed throughout the body at the time of death.

• Organ tissue: Organs such as the liver, brain, kidney, and spleen are often retrieved during an autopsy. Toxic or poisonous metals can collect in some of these tissues if they are present. The lungs may show the presence of inhaled toxins, and other organs may be affected by poisons depending on the type of poison.

• Gastric contents: If death occurred quickly from a poison or toxin that was ingested, there may be evidence, such as undigested pills or capsules, in the stomach.

• Hair: Although other samples may be most useful for determining that poisoning has happened, hair can provide some indication of past exposure to toxins or poisons. In some cases, it may also provide some information on how long the exposure has been going on. While poisons can sometimes be detected in hair for long periods of time, it is important to note that the results can be tainted by external sources.

• Bone: In some cases, the skeletal remains may be the only aspect left. Drugs and other substances have been identified from bones, although other samples are typically preferred. Bones may provide evidence of some metals, as they tend to accumulate in bones. Bone marrow may also provide some evidence of toxins.

After obtaining a sample, a medical examiner or forensic scientist is ready to begin testing for the presence of different poisons and toxins. The analysis may include some that are also used to test for drugs, such as spectrophotometry or color tests. Cyanide, for example, can be detected using a simple color test. Different forms of chromatography are also used to separate the different compounds in a sample, which can also show the presence of poisons or toxins. Chromatography can help identify the quantity of poison or toxin contained in a sample, as well as the presence of the poison.

As the testing differs depending on the sample and the suspected poison or toxin, let's take a closer look at a couple of common poisons and how they can be detected. Carbon monoxide is one of the leading causes of accidental poisoning and is one of the most common toxic substances that forensic scientists have to deal with. When carbon monoxide enters the body, red blood cells absorb it. It then combines with the hemoglobin present, forming carboxyhemoglobin. Normally, hemoglobin combines with oxygen, and this is how oxygen is transported throughout the body. When there is a high concentration of carbon monoxide combining with the hemoglobin, not enough oxygen is carried through the body and death soon follows.

When examining whether someone died from carbon monoxide, forensic scientists look at the percent saturation. The **percent saturation** is the ratio of hemoglobin that has been combined with carbon monoxide in comparison to hemoglobin that has been combined with oxygen. The exact level of carbon monoxide toxicity is dependent on factors such as age, fitness level, health, and so on. One of the reasons the percent saturation is an important aspect to know is that it can help determine whether someone died from carbon monoxide poisoning or another cause before carbon monoxide was introduced. For example, imagine that you are a forensic scientist examining a fire victim. A higher percent saturation would indicate that the person breathed in carbon monoxide and may have died from that cause. A lower percent saturation may indicate that the individual was dead before the fire started.

To test for carbon monoxide poisoning, a forensic scientist has a couple of options. One option is to use a spectrophotometer and record the absorption of light in the sample of blood to see whether it contains more carbon monoxide or oxygen in the hemoglobin. Another method is to use a reagent in the blood, which will release the carbon monoxide. The carbon monoxide can then be placed in a gas chromatography machine and measured.

Poisons can also be detected in other ways as well. Heavy metals, including arsenic, thallium, and mercury, are not commonly used as poisons anymore, but they do show up from time to time in poisoning cases. To test for the presence of heavy metals, a forensic scientist can take a sample of tissue or bodily fluid and place the sample in hydrochloric acid. The **Reinsch test** is then used, which consists of placing a copper strip into the solution. If the copper strip develops either a dark or silver coating, heavy metals are in the sample. The sample will then be submitted to further testing, such as spectrophotometry, in order to confirm the finding and identify the particular heavy metal that is present. The use of these advanced devices makes the identification of poisons like arsenic much easier today than it was several hundred years ago.

We have learned about forensic toxicology, about its history and how the field developed over time. We also discussed some common substances that have been used to intentionally poison others and why these substances are chosen. Finally, we looked at how forensic scientists test for some of these poisons, including some of the different samples that can be taken from a body for testing.